# Neuroeconomics

How our brain decides
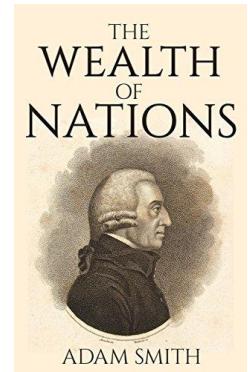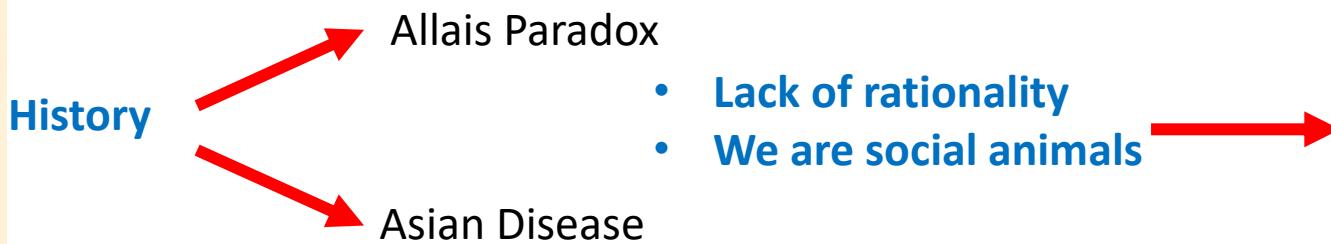
Summary

- **Low level decisions: Perceptual and Motion Decisions**
  - Model that describe these processes (diffusion)
  - Brain regions that codify these processes

- High level decision making processes based on:
  - Utility
  - Probability
  - Emotion

Conceptual map

History

Allais Paradox

Asian Disease

- **Lack of rationality**
- **We are social animals**
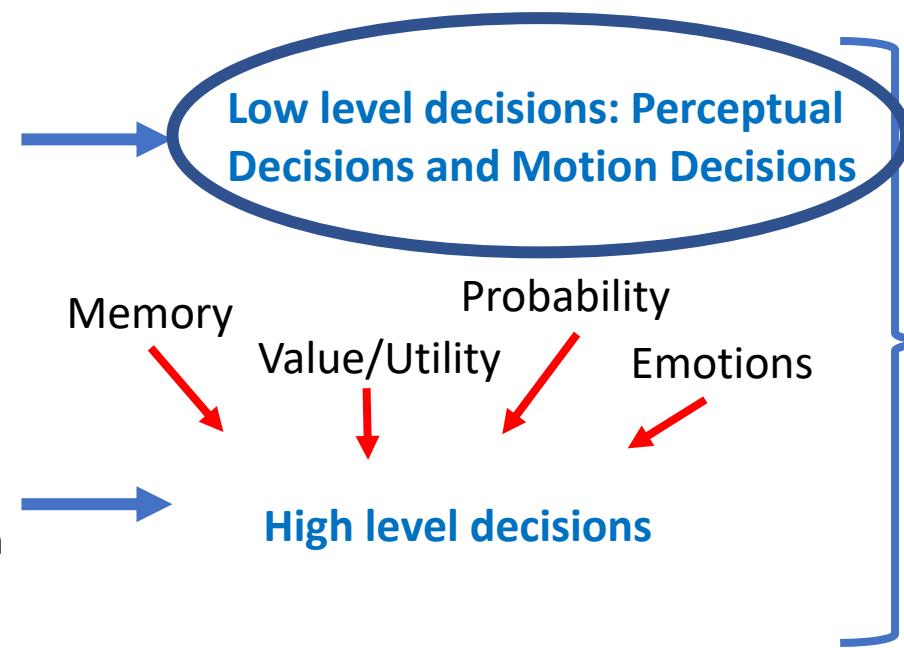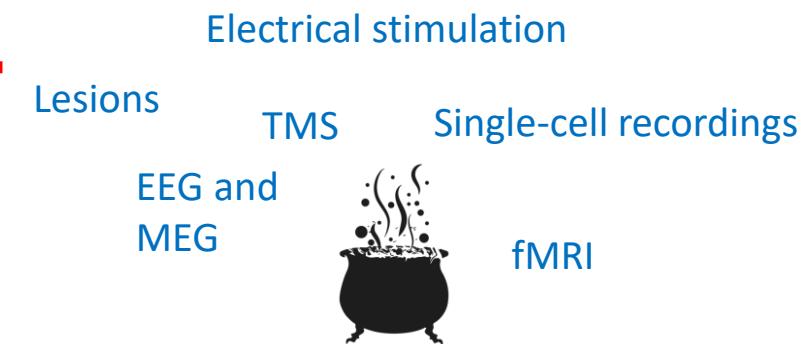
Study DECISION MAKING using psychology and neuroscience:

1) Options
2) Not random decisions
3) Goal-directed

METHODS of neuroeconomic and decision making

Inferior parietal lobe

Lateral intraparietal area

Low level decisions: Perceptual Decisions and Motion Decisions

Memory

Probability

Value/Utility   Emotions

Orbitofrontal cortex → options

Ventrolateral cortex → selfcontrol

DLPFC → planning and organization

aCC → learning consequences

High level decisions

Electrical stimulation

Lesions

TMS   Single-cell recordings

EEG and MEG

fMRI

Decisions start from sensory elaboration
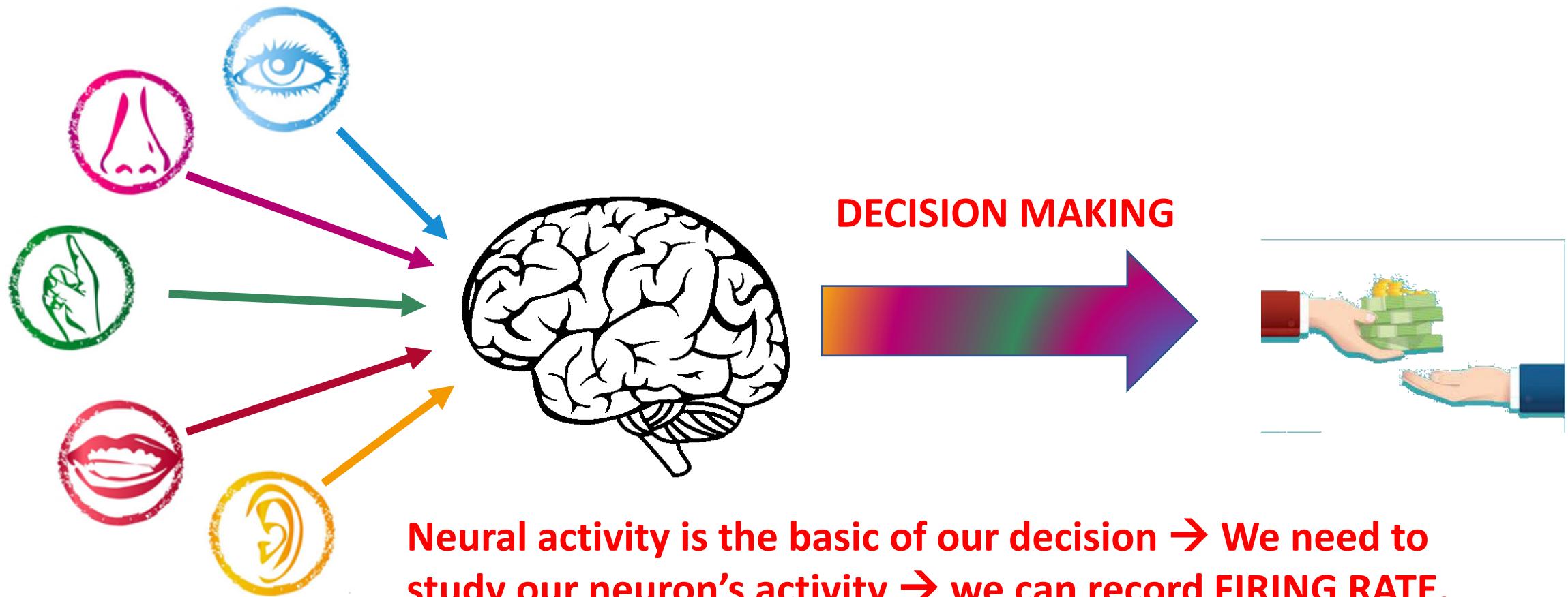
Neuroeconomics is trying to understand how sensory information are transformed into decisions.

DECISION MAKING

We need to collect and elaborate information of sensory inputs → estimate of alternatives → make decision

How sensory information is transformed into decisions?
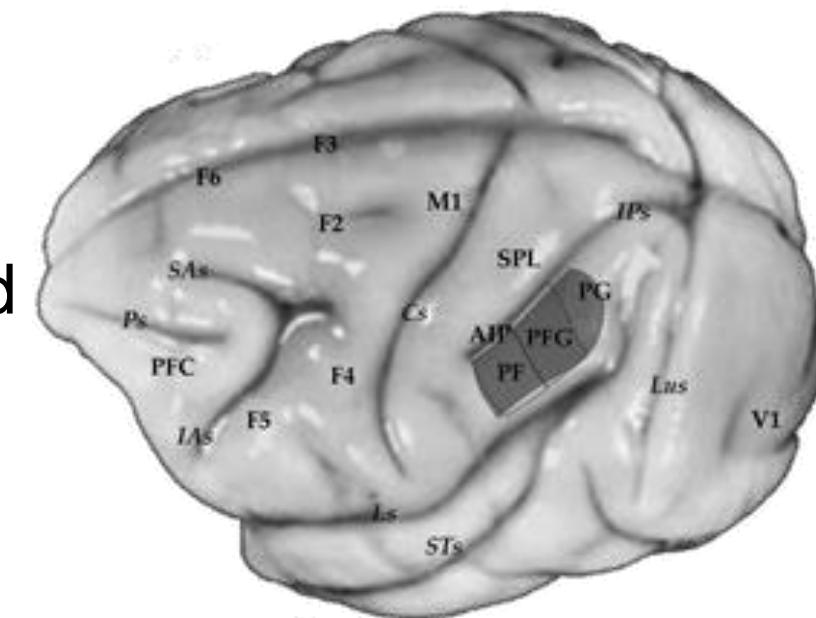
DECISION MAKING

Neural activity is the basic of our decision → We need to study our neuron's activity → we can record FIRING RATE, that can indicate a specific process of decision making

FIRING RATE

Neuronal Chains for Actions in the Parietal Lobe: A Computational Model

Fabian Chersi[1,2]*, Pier Francesco Ferrari[2,3,5], Leonardo Fogassi[2,4,5]
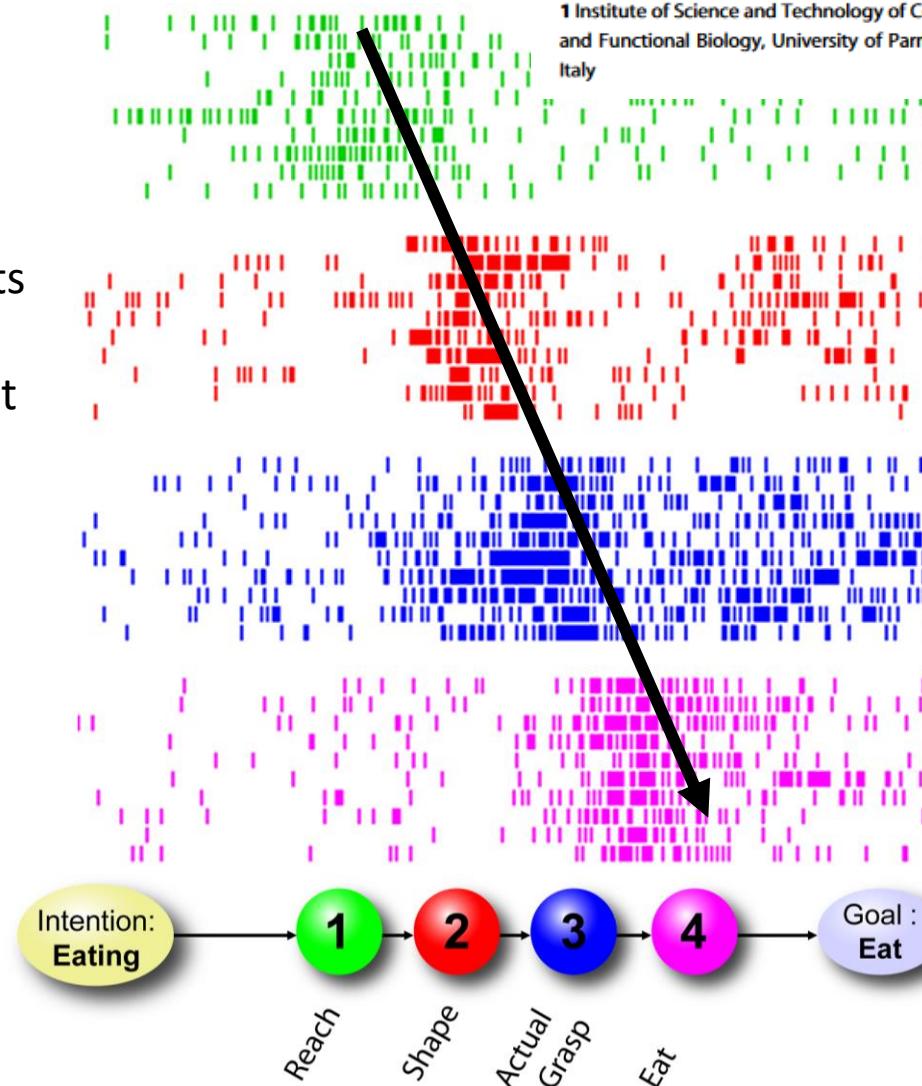
1 Institute of Science and Technology of Cognition, CNR Rome, Rome, Italy, 2 Department of Neuroscience, University of Parma, Parma, Italy, 3 Department of Evolutionary and Functional Biology, University of Parma, Parma, Italy, 4 Department of Psychology, University of Parma, Parma, Italy, 5 Italian Institute of Technology (RTM), Parma, Italy

- The **inferior** part of the **parietal lobe** (IPL) is known to play a very important role in sensorimotor integration.

- Neurons in this region code goal-related motor acts performed with the <u>mouth</u>, with the <u>hand</u> and with the <u>arm</u>.

- It has been demonstrated that most **IPL motor neurons** coding a specific motor act (e.g., grasping) **show markedly different activation** patterns according **to the final goal** of the action sequence in which the act is embedded (grasping for eating or grasping for placing).

FIRING RATE

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- Each line represents a trial.
- We have 4 different neurons
- We see groups of spikes at certain time points
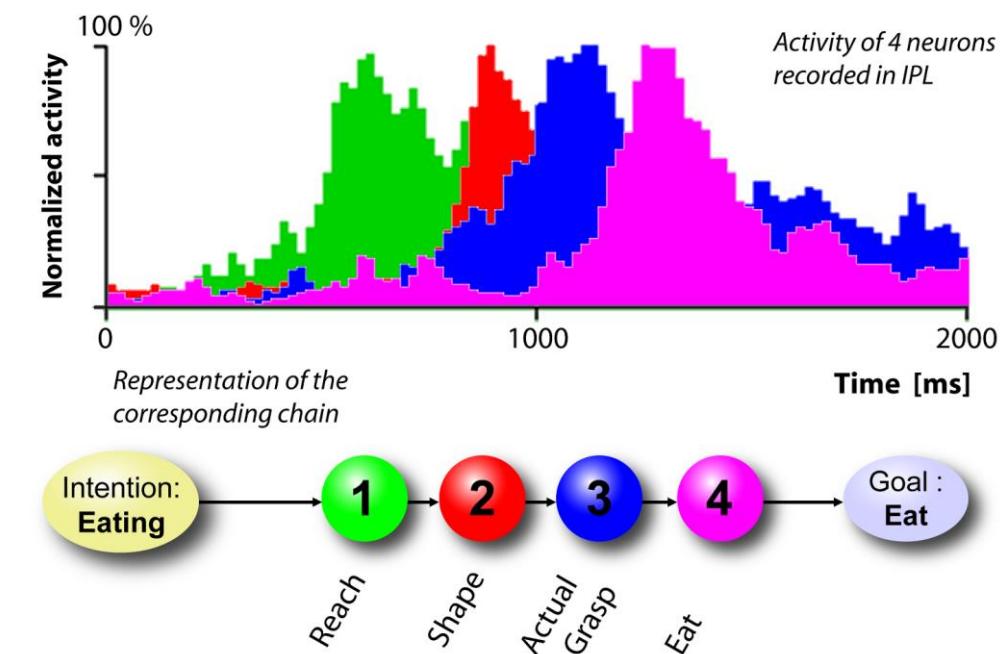
Figure 4. Time course of the activity of 4 neurons recorded in IPL. **Each one codes a specific motor act**, but is active only when the monkey executes the "grasping to eat" sequence. Both rasters and histograms are aligned with the moment in which the monkey touches the object. Beneath the histograms a schematic representation of the corresponding neuronal chain is shown.
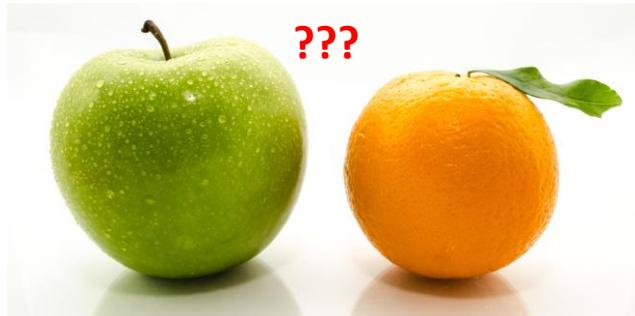
Decisions

???

???

Different decisions

???

???

We need to find simple decisions in order to study the neurobiology of decision making

Decisions

- Cognitive neuroscience has made great progress regarding the neural basis of **perceptual** and **motion** decision making.

- Models of decision making, based largely on single cell firing in monkeys, assumes that neurons encode a sequential probability ratio test (SPRT) (Barnard, 1946, Good, 1979, Wald, 1947).

Example of simple decisions: Perceptual decisions

- Perceptual decision making is the process by which **sensory information is used to guide behavior** toward the external world. This involves **gathering** information through the senses, **evaluating** and **integrating** information according to the current goals and internal state of the subject, and **using** information to produce motor responses

- The aim of the decision-maker is to **categorize ambiguous** (or noisy) sensory information

Perceptual decisions

Perceptual decisions
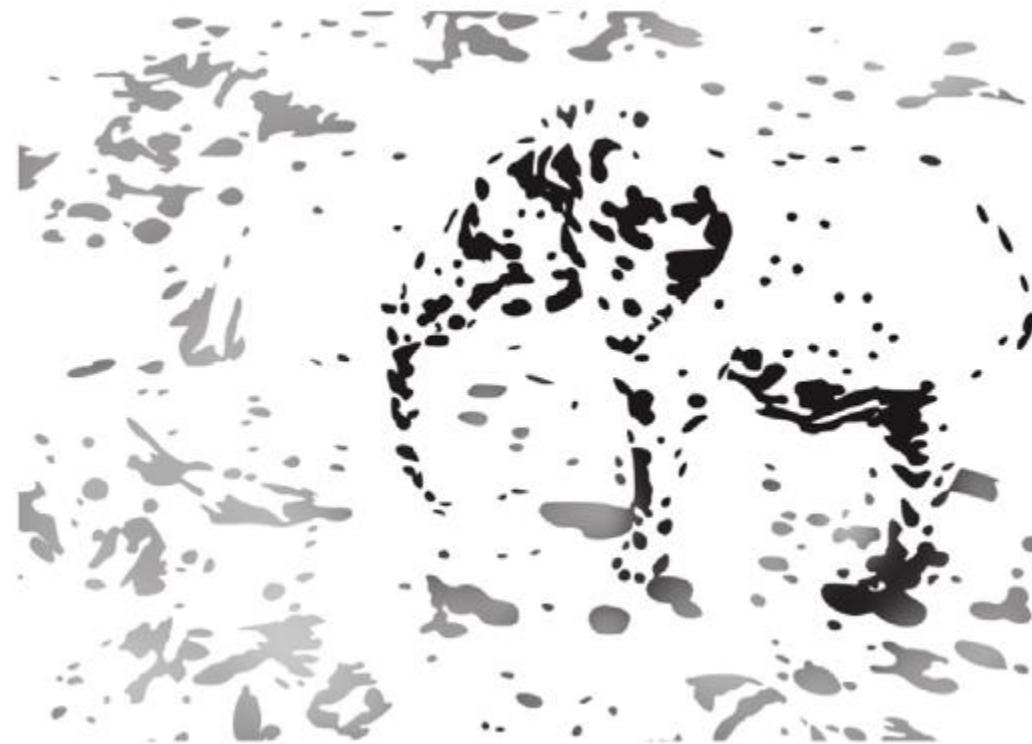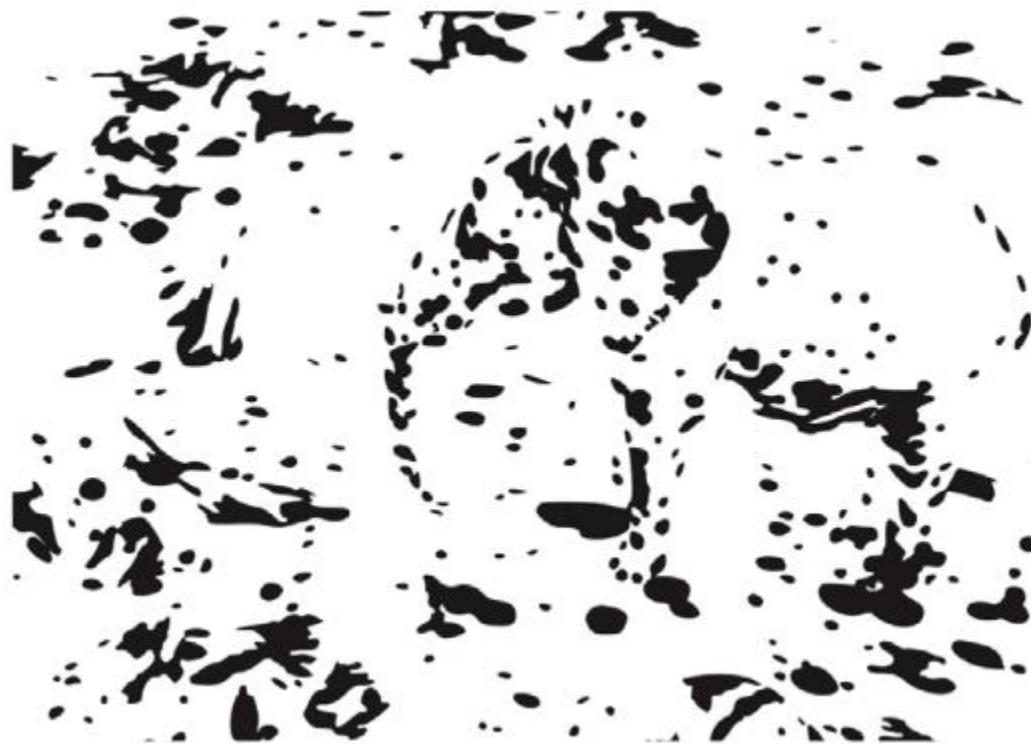
hidden Dalmatian

Perceptual decisions
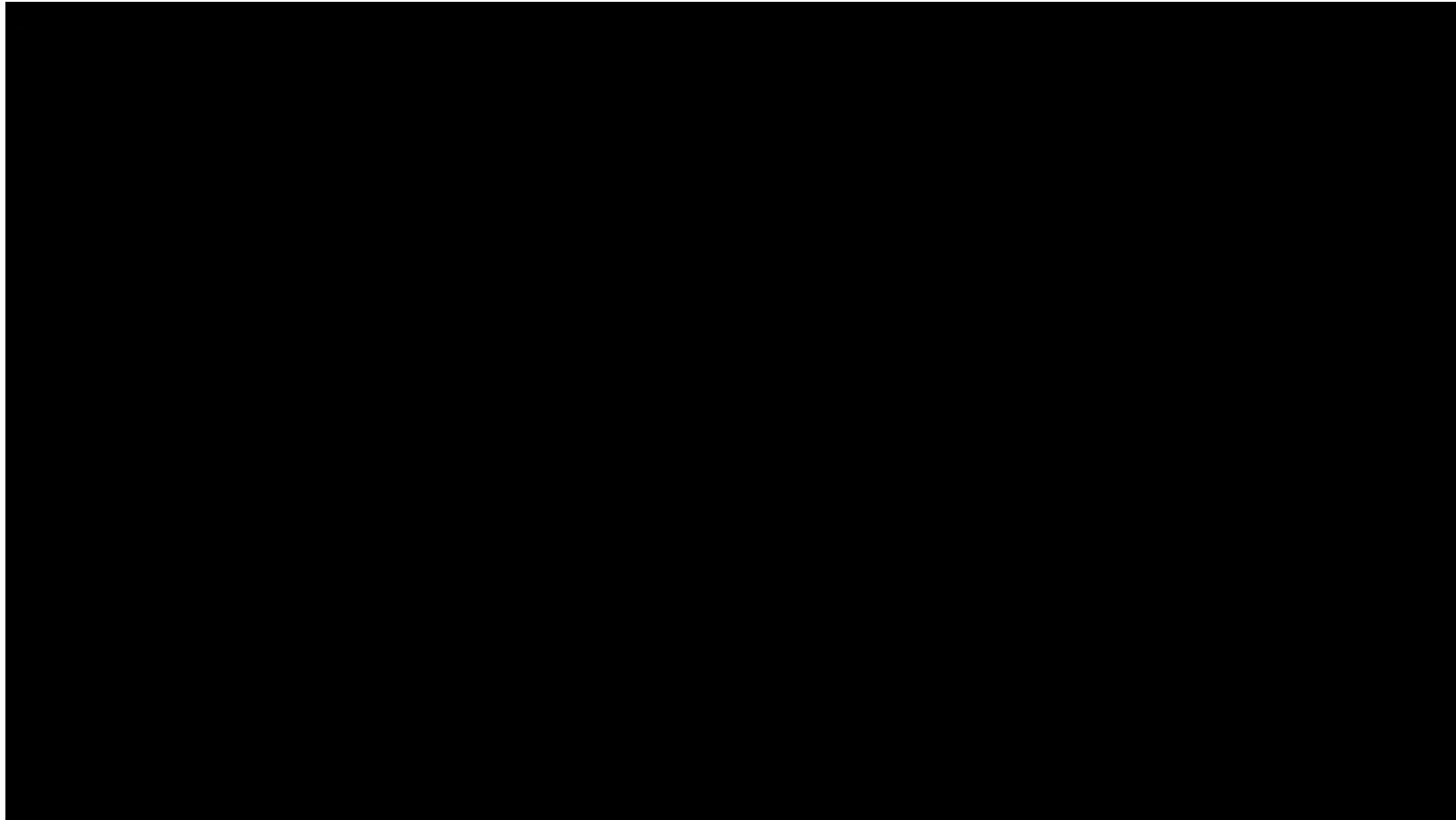
Perceptual decisions

hidden Elephant

Motion perception

Perceptual decisions and motion

- Our brain is very sensitive to perceptual decisions and motion, and there are specialized neurons that code these decisions.

Perceptual discrimination task

- Authors have measured the performance of monkeys and of visual cortical neurons while the animals performed a psychophysical task well matched to the properties of the neurons under study.
- Animals were trained to report the direction of motion of dots presented on a screen.
- Some dots moved coherently while the others moved at random.
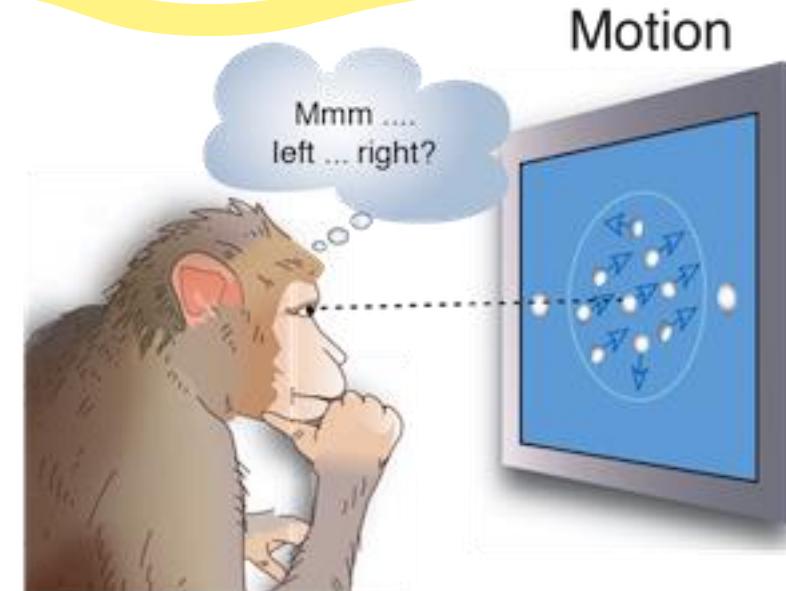
Neuronal correlates of a perceptual decision

William T. Newsome*†, Kenneth H. Britten*†
& J. Anthony Movshon‡

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‡ Department of Psychology and Center for Neural Science, New York University, New York 10003, USA

Motion

Mmm .....
left ... right?
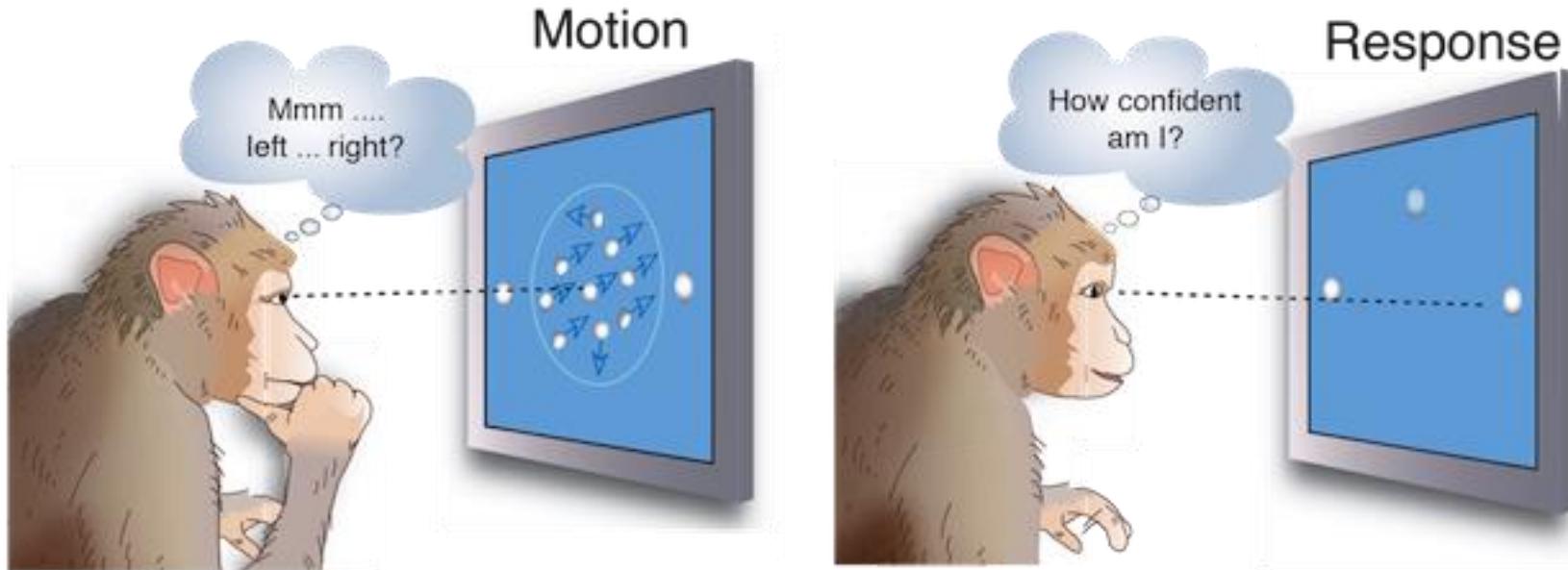
Perceptual discrimination task

The monkey has to switch gaze right or left, following the movement direction of the majority of the dots presented on the screen.

- If the majority of dots are moving right → animal has to switch gaze right.
- If the majority of dots are moving left → animal has to switch gaze left.
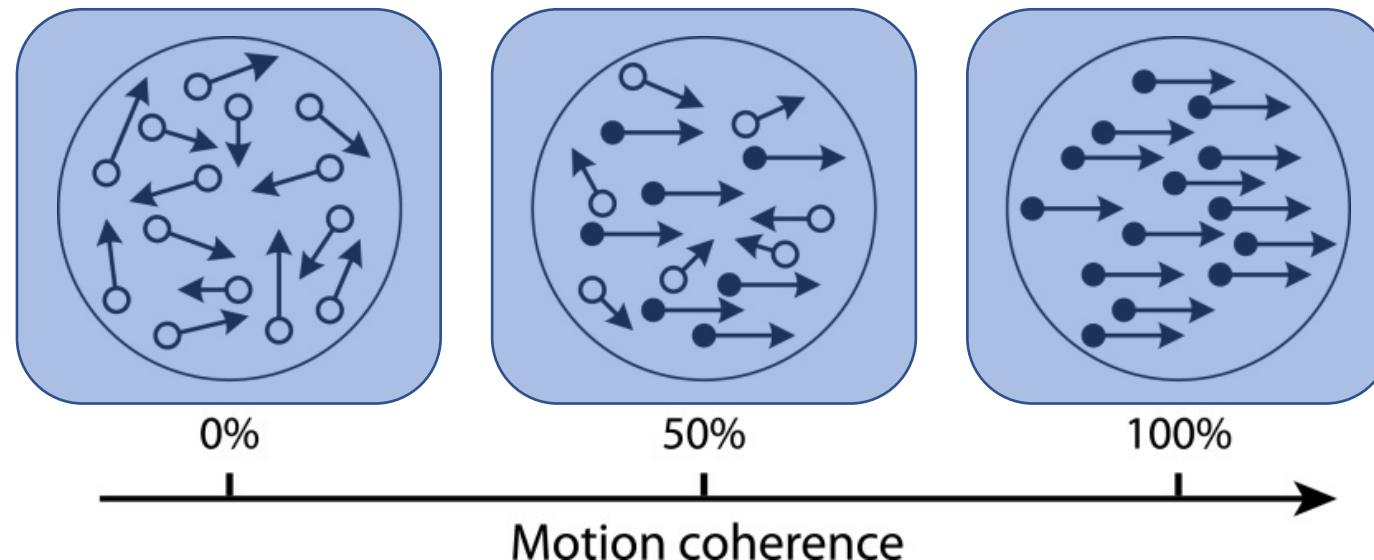
Perceptual discrimination task

The effects of evidence bounds on decision-making: theoretical and empirical developments
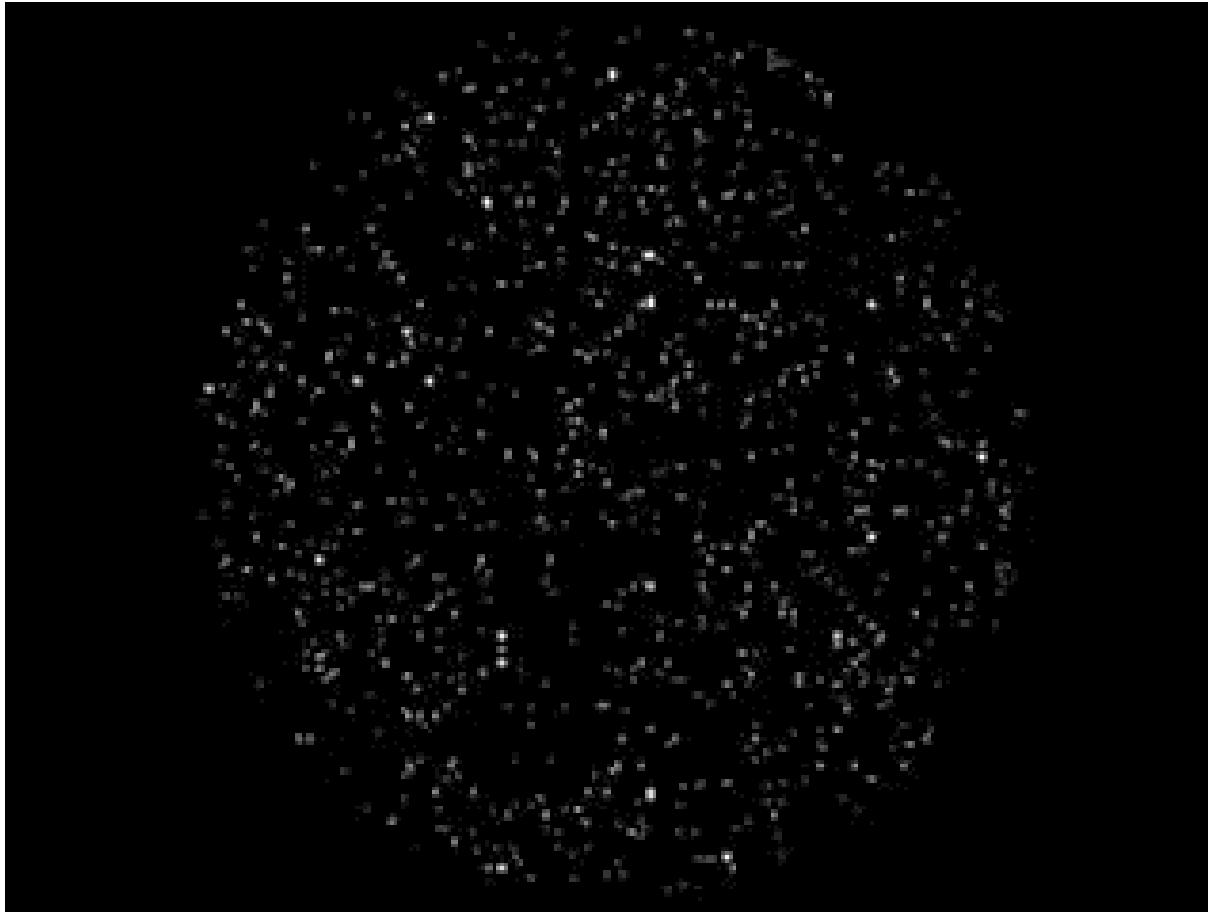
*Jiaxiang Zhang**

Cognition and Brain Sciences Unit, Medical Research Council, Cambridge, UK

0%   50%   100%
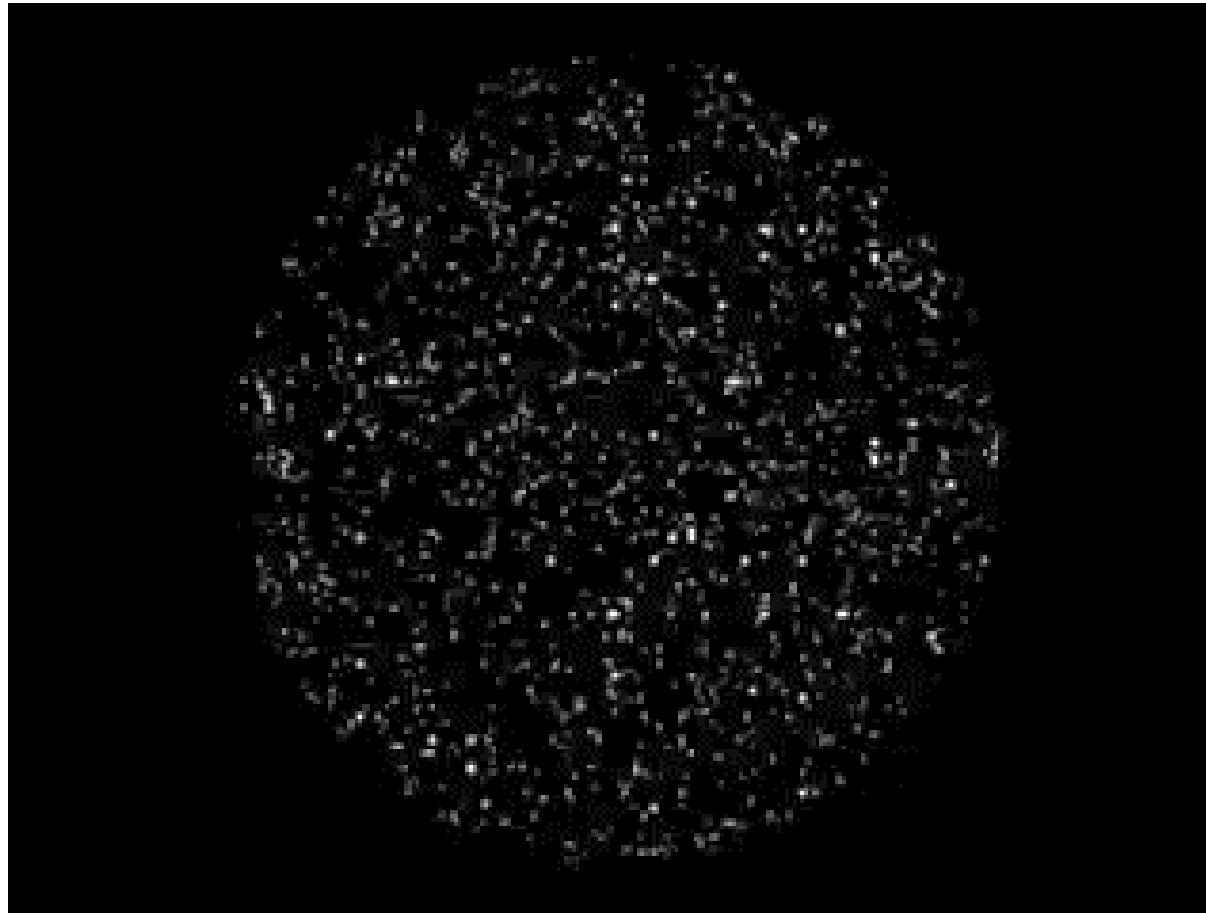
Motion coherence

- It is possible to manipulate the percentage of dots moving in a direction → we can increase the difficulty of the task.
- In the 0% motion coherence → dots are moving in random order → Monkey couldn't make it as it is a very difficult perceptual decision task
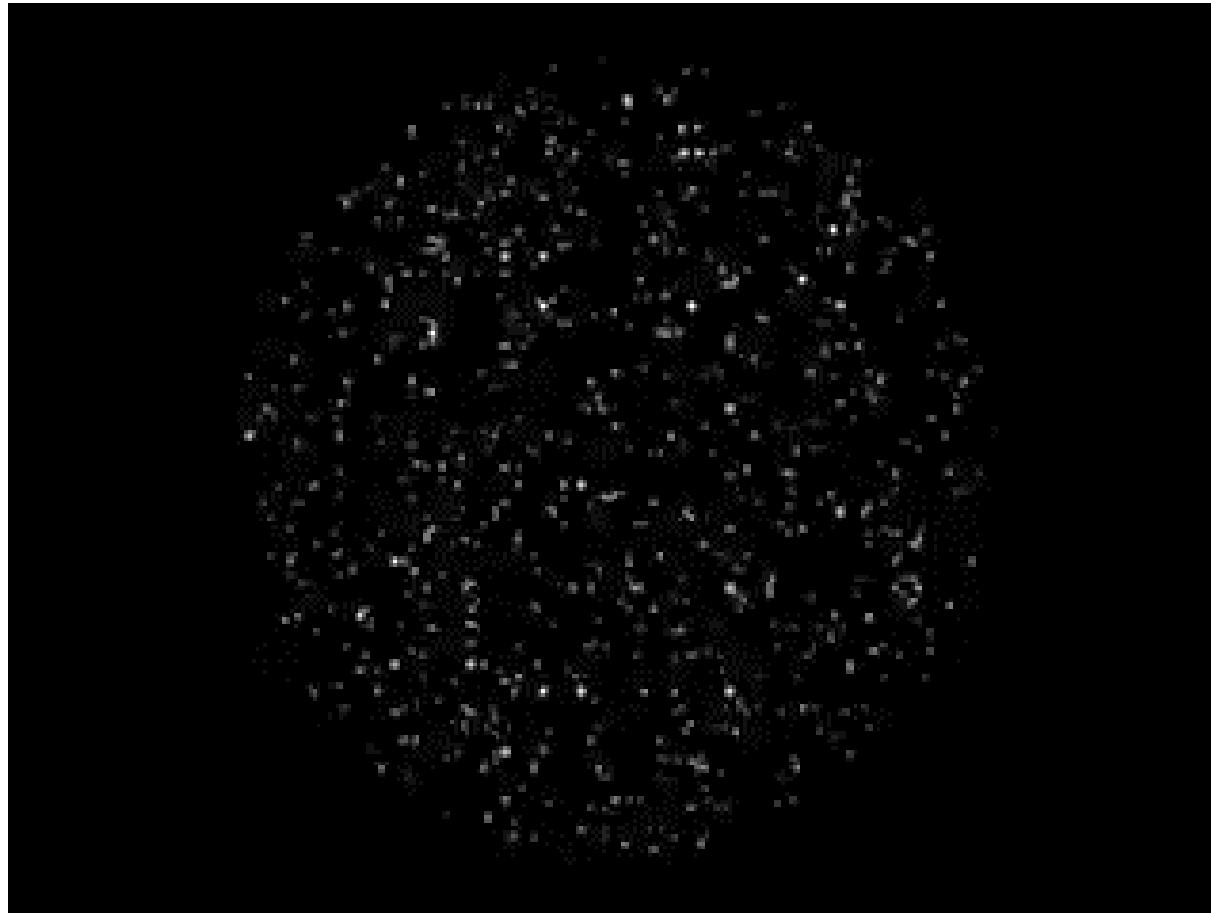
# 100 % Coherence example

30 % Coherence example
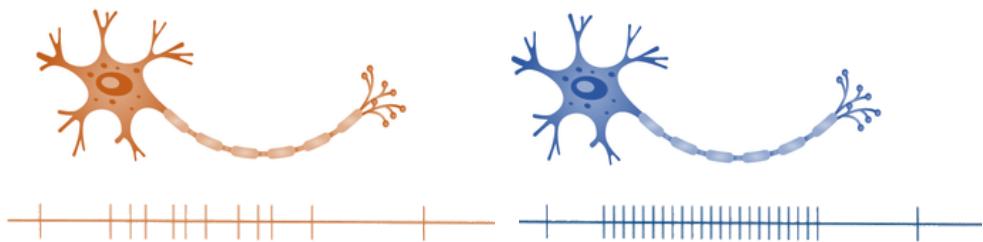
0 % Coherence example

Perceptual discrimination task

Neuronal correlates of a perceptual decision

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New York University, New York 10003, USA

- Motion information projects to the retina
- Information reaches the visual cortex in which there are "motion detectors", neurons that are sensitive to motion (Left and Right)
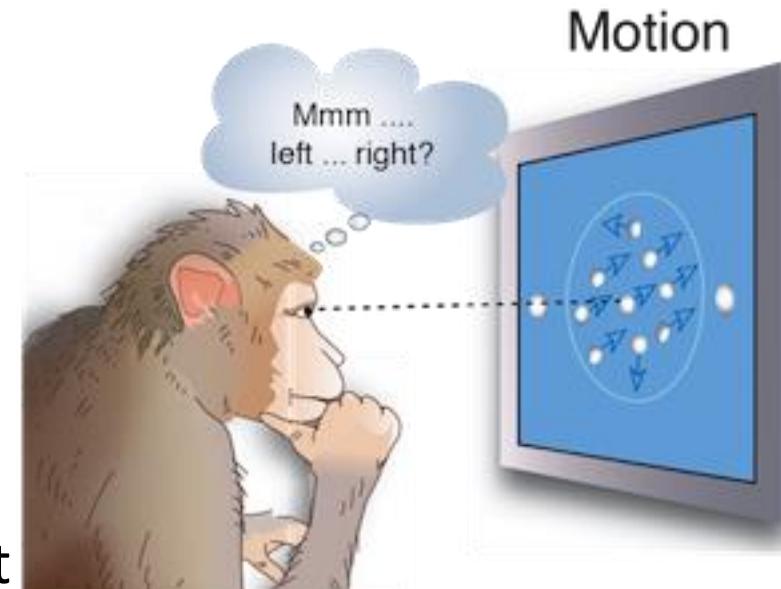

- The activity of these neurons is proportional to the amount of motion on the screen.
- **A network of neurons compares** Left vs Right
- Than we have the decision.

Motion

Mmm ....
left ... right?

Perceptual discrimination task

Neuronal correlates of a perceptual decision

William T. Newsome*†, Kenneth H. Britten*†
& J. Anthony Movshon‡

* Department of Neurobiology and Behavior, State University of New York,
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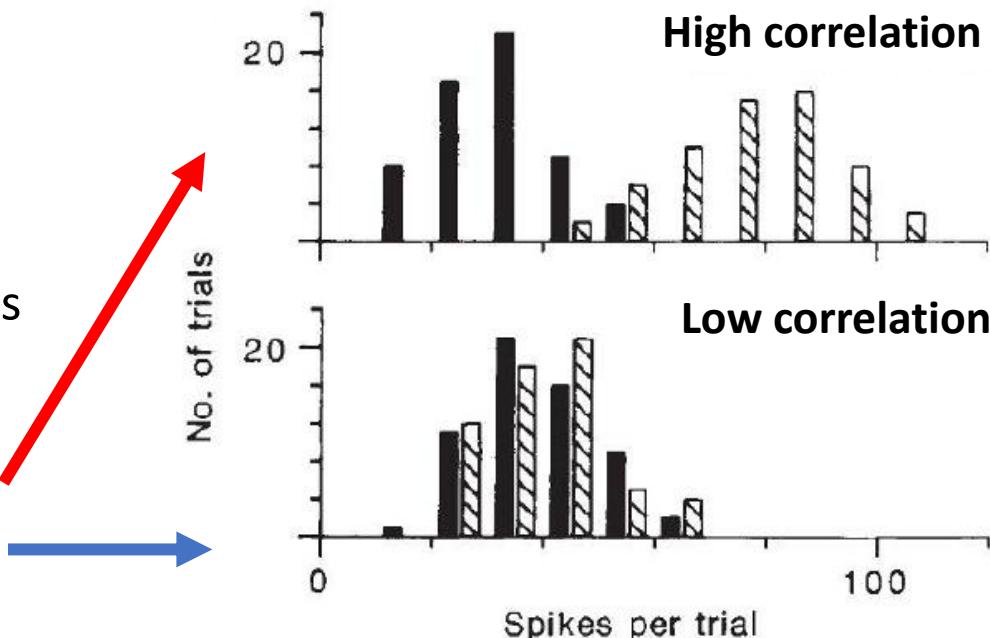
- The authors recorded single neuron activity from area MT, mediotemporal, (V5), a region of the extrastriate visual cortex concerned with motion processing, where most neurons respond optimally to visual stimuli of a **particular direction** and **speed** of motion.

- At low correlation, the monkey chose the correct direction only on about half the trials (random performance)

- At high correlation, monkey's performance was nearly perfect

- **The network of neurons decides for "black"**
- **The network decides by random choice**
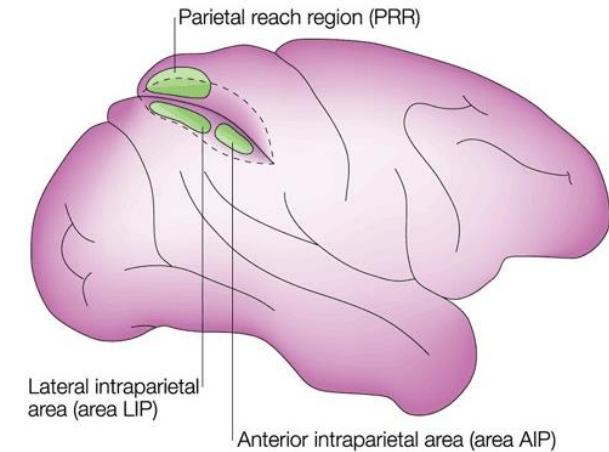
Stimulation of LIP ➔ affects this decision

Microstimulation of macaque area LIP affects decision-making in a motion discrimination task

Timothy D. Hanks[1], Jochen Ditterich[1,2], and Michael N. Shadlen[1,*]

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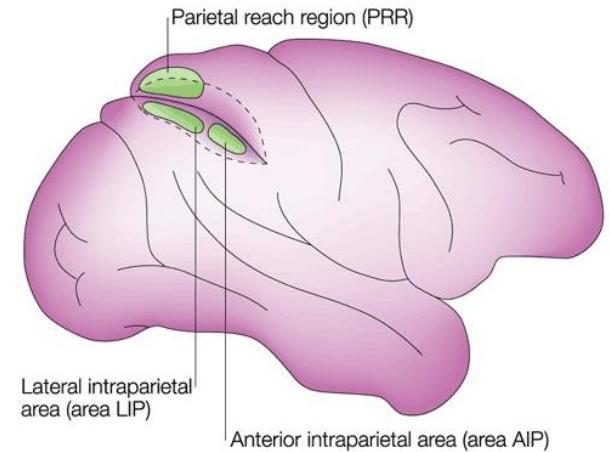
[2]Center for Neuroscience, University of California, Davis, California 95616, USA

Parietal reach region (PRR)

Lateral intraparietal area (area LIP)

Anterior intraparietal area (area AIP)

- Aim of the study: Recent physiological studies suggest that neurons in association areas may be involved in decision-making process. To test this, the authors measured **the effects of electrical microstimulation in the lateral intraparietal area (LIP)** while monkeys performed a reaction-time motion discrimination task with a saccadic response.

Stimulation of LIP → affects this decision
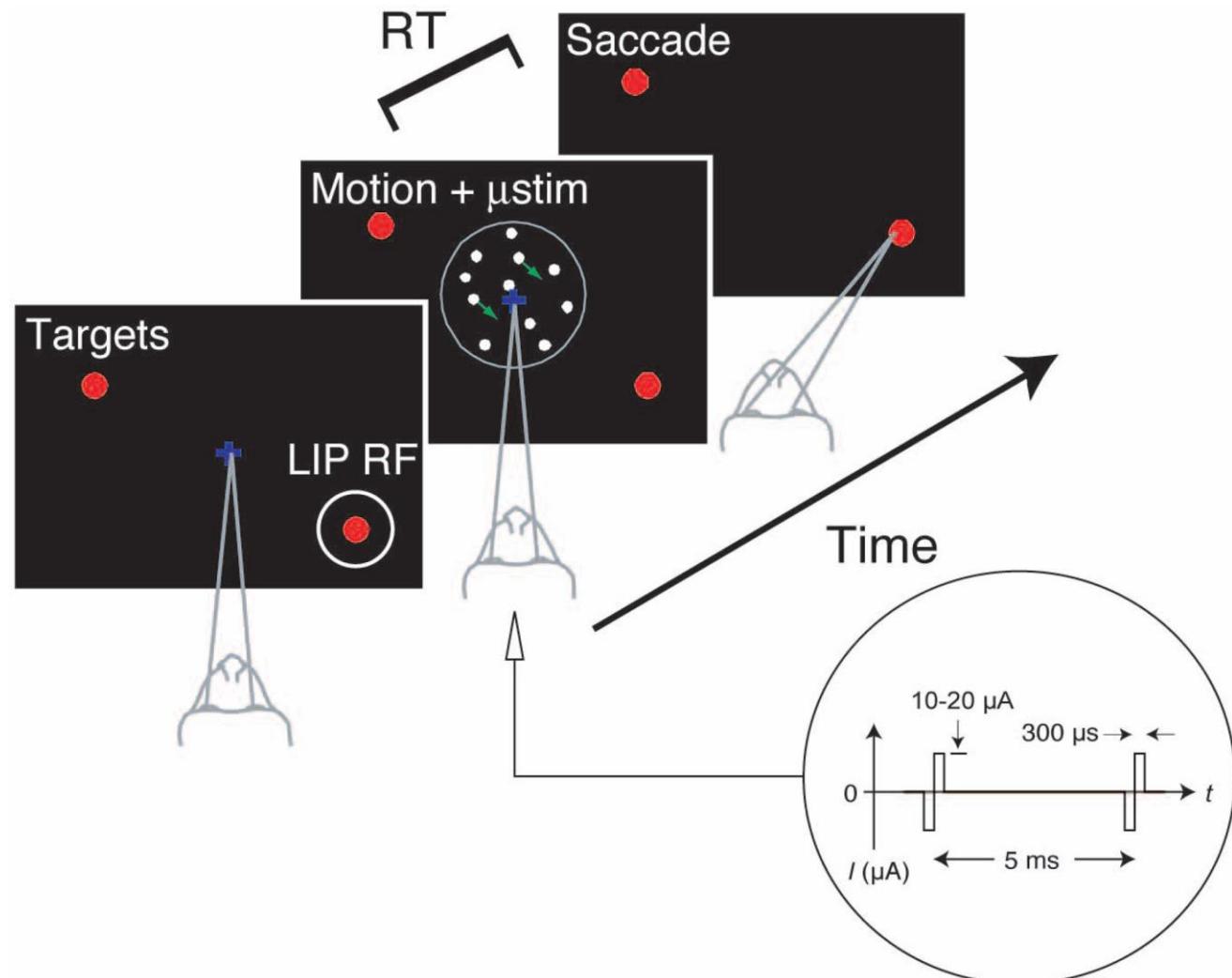
- When monkeys indicate decisions about direction of motion with an eye movement, LIP neurons increase or decrease their firing as evidence accumulates in favor of or against the choice associated with the target in their response field (RF)

- Neurons in LIP appear to represent the mounting evidence for or against an eye movement to the choice target in their RF

Parietal reach region (PRR)

Lateral intraparietal area (area LIP)

Anterior intraparietal area (area AIP)

Stimulation of LIP → affects this decision

Monkeys were trained to perform a two choice direction discrimination task while viewing a random-dot motion stimulus

Fig. 1. Experimental Design. A recording/stimulating **microelectrode** was advanced into the ventral portion of area **LIP** to identify a cluster of neurons with response fields (RFs) and sustained activity during memory-guided saccades. The monkey performed a direction discrimination task with **several levels of task difficulty** randomly interleaved. The monkey could respond at any time after onset of the random dot motion and it indicated its decision with a saccadic eye movement. One of the two choice targets was placed in the RF of the LIP neurons. **We applied microstimulation as shown from the onset of the motion stimulus until the initiation of the saccade** on a random half of the trials.

Microstimulation of this **lateral intraparietal area** cluster caused an increase in the proportion of choices to the response field of the stimulated neurons.
Choices toward the stimulated RF were faster with microstimulation, while choices in the opposite direction were slower.
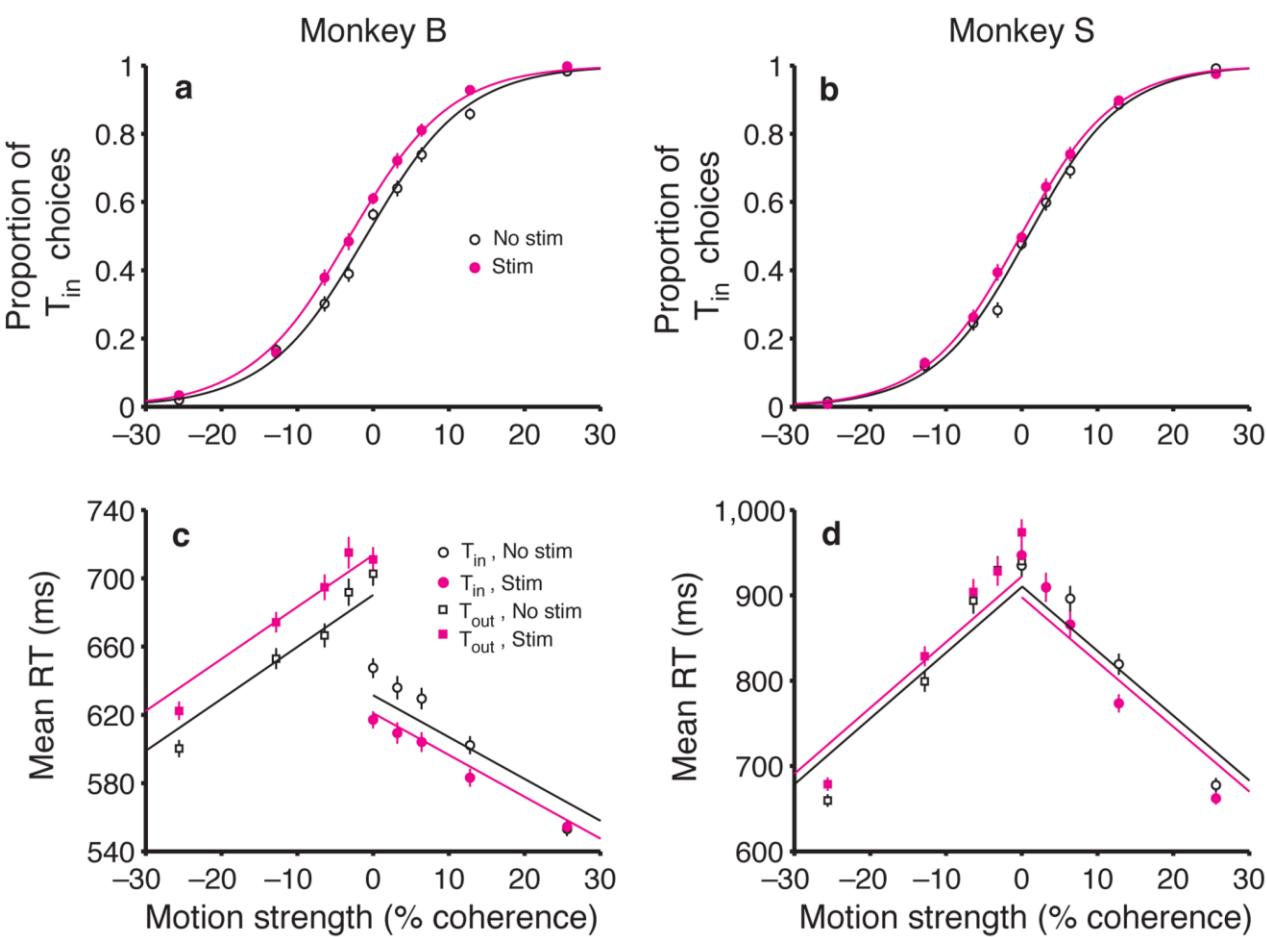

Fig. 2.
Microstimulation in LIP affects both decisions and reaction times. (**a**, **b**) Effect of motion strength and LIP microstimulation on monkeys' choices. The probability of a T_{in} choice is plotted as a function of motion strength. Positive and negative motion strengths correspond to motion toward T_{in} and T_{out}, respectively. The sigmoid curves are fit using equation 1, which characterizes the microstimulation effect as a horizontal shift of the psychometric function. (**c**, **d**) Effect of motion strength and LIP microstimulation on reaction time. Average RTs ($\pm$ SEM) are plotted as a function of motion strength for all correct trials.

Diffusion models

The Diffusion Decision Model: Theory and Data for Two-Choice Decision Tasks

Roger Ratcliff and Gail McKoon

- Diffusion models (Ratcliff, 1978) explain this simple, two-choice decision making process.

- The diffusion model is a model of the cognitive processes involved in simple two-choice decisions.

- The model should be applied only to relatively fast low-choice decisions (mean RTs less than about 1000 to 1500 ms) and only to decisions that are a single-stage decision process.

Diffusion models

## The Diffusion Decision Model: Theory and Data for Two-Choice Decision Tasks

Roger Ratcliff and Gail McKoon

- The diffusion model assumes that **decisions are made** by a noisy process that accumulates information over time from a starting point toward one of two response criteria or boundaries.
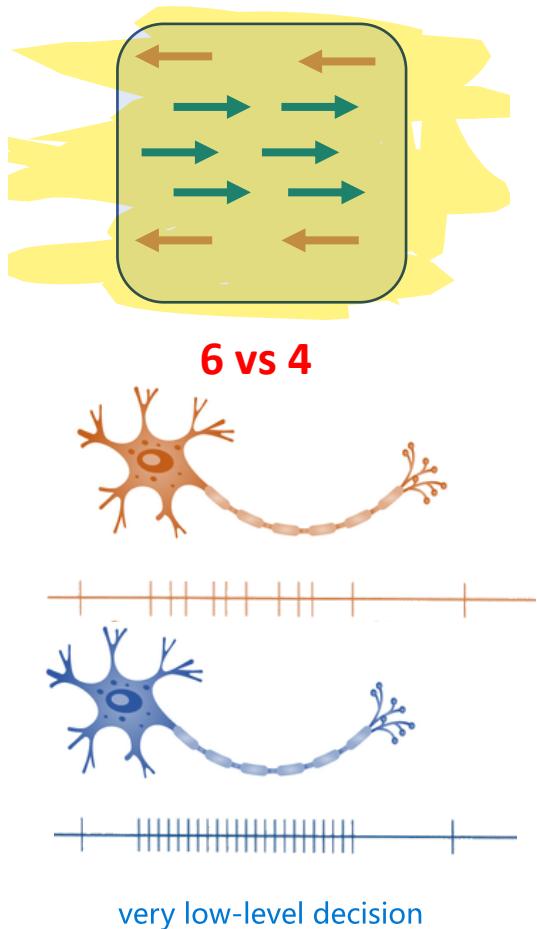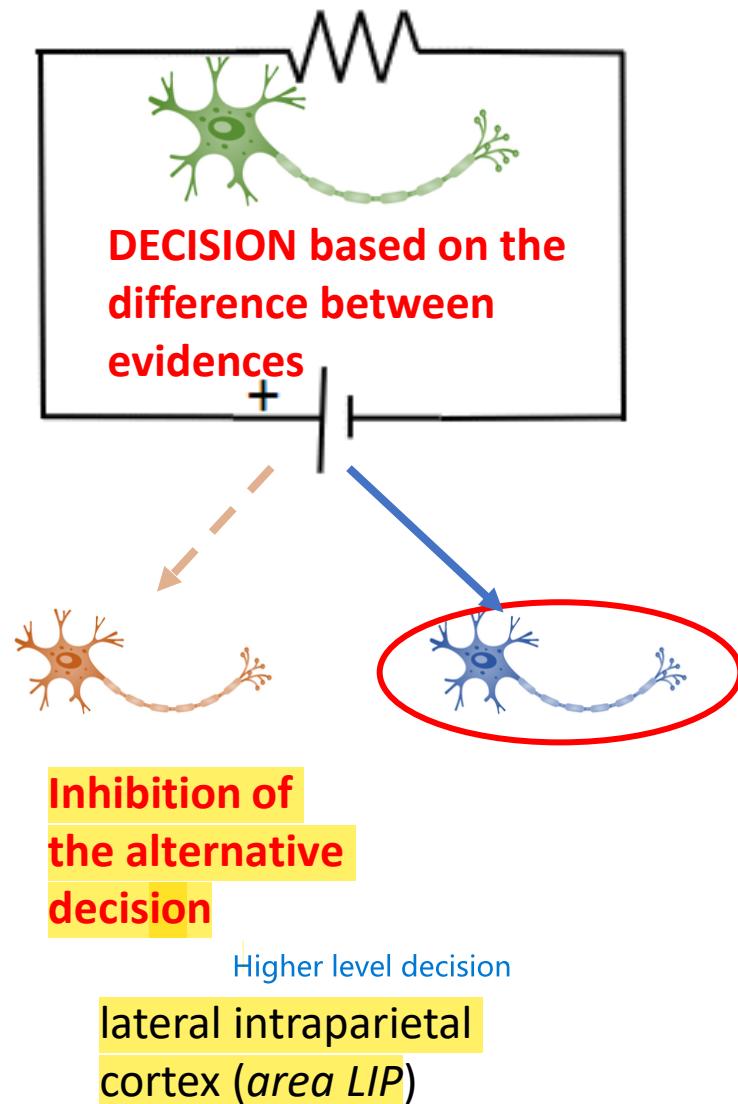
- The starting point is labeled **z** and the boundaries are labeled **a** and **0**.

- **When one of the boundaries is reached, a response is initiated**. The rate of accumulation of information is called the drift rate (v), and it is determined by the quality of the information extracted from the stimulus.

Diffusion model

6 vs 4

very low-level decision

MT, mediotemporal, (V5)

DECISION based on the difference between evidences

Inhibition of the alternative decision

Higher level decision
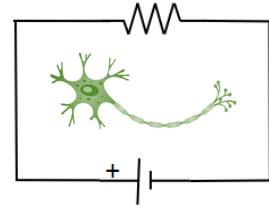
lateral intraparietal cortex (*area LIP*)

real area that produce teh decision process

Activation of motor neurons in the FEF (frontal eye field, area 8)

Examples of these models in 2 situations that differ for the amount of evidences

- The diffusion model reacts adaptively to the levels of evidences of the alternative:

  - Short decision making reaction time if the alternatives are different
  - Long decision making reaction time if the alternatives are similar

- This "plasticity" is a characteristic of the diffusion model.
- Neurons use the diffusion model.

Diffusion

Perceptual decision making in the brain

- When monkeys must decide whether a noisy field of dots is moving upward or downward, a decision can be formed by computing the difference in responses between lower-level neurons sensitive to upward motion and those sensitive to downward motion

- Is there a similar mechanism at work for **more complex decisions** in the **human brain**?

Perceptual decision making in the brain

A general mechanism for perceptual decision-making in the human brain

H. R. Heekeren[1], S. Marrett[2], P. A. Bandettini[1,2] & L. G. Ungerleider[1]

[1]Laboratory of Brain and Cognition, NIMH, [2]Functional MRI Facility, NIMH, NIH, Bethesda, Maryland 20892-1148, USA
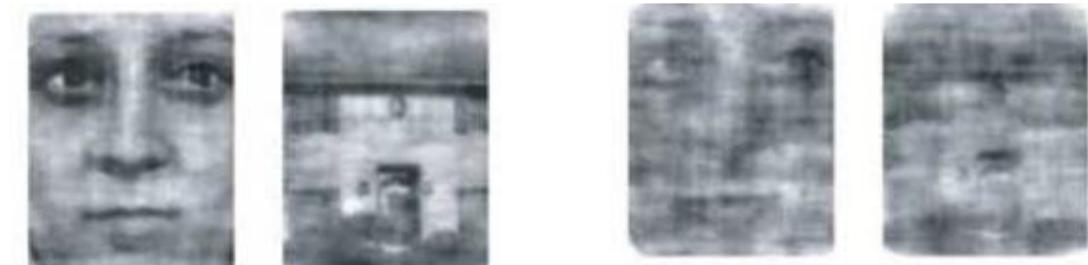
- We can **apply** the **diffusion** model to **human** decision making processes.

- Findings from single-cell recording studies suggest that a **comparison of the outputs** of different pools of sensory neurons may be a **general mechanism** by which higher-level brain regions compute perceptual decisions.

- Task: subjects decide whether an image presented is a face or a house
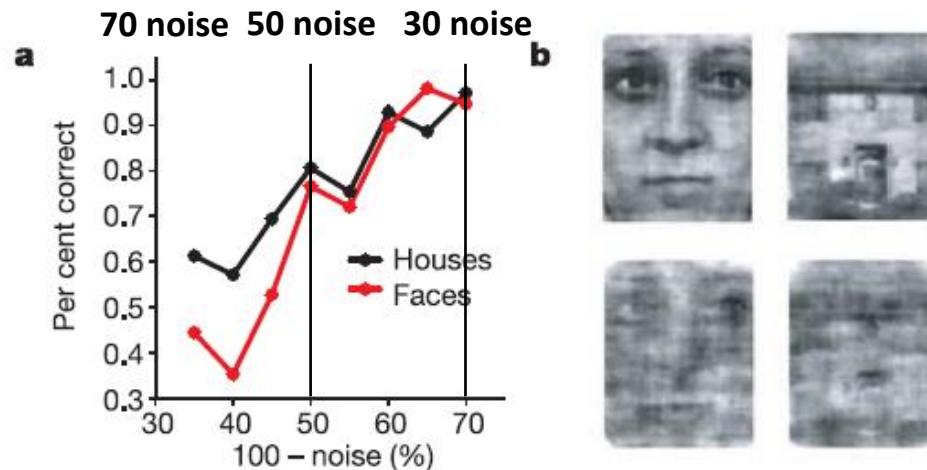
- To test the model of decision-making, the authors **added noise** to the face and house stimuli, which made the task arbitrarily more difficult by reducing the sensory evidence available to the subject

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70 noise 50 noise 30 noise

Figure 1 Experimental task. Subjects decided whether an image presented on a screen was a face or a house. By adding noise, the amount of sensory evidence in the stimuli was varied parametrically. **a**, Results of behavioural study to assess the amount of noise to add to the images. Thresholds (82% correct) were about 45% noise for both faces and houses. **b**, In the fMRI experiment, we used images of faces and houses that were either easy (95% correct, suprathreshold, **b** top) or difficult (82% correct, perithreshold, **b** bottom). **c**, Rapid event-related fMRI design. Stimuli were presented for 1 s, subjects responded with a button press after a forced delay (response cue shown for 300 ms, delay 1–5 s).

Subjects viewed images that were either easy (**suprathreshold**, Fig. 1b top) or difficult (**perithreshold**, Fig. 1b bottom) to identify as faces or houses

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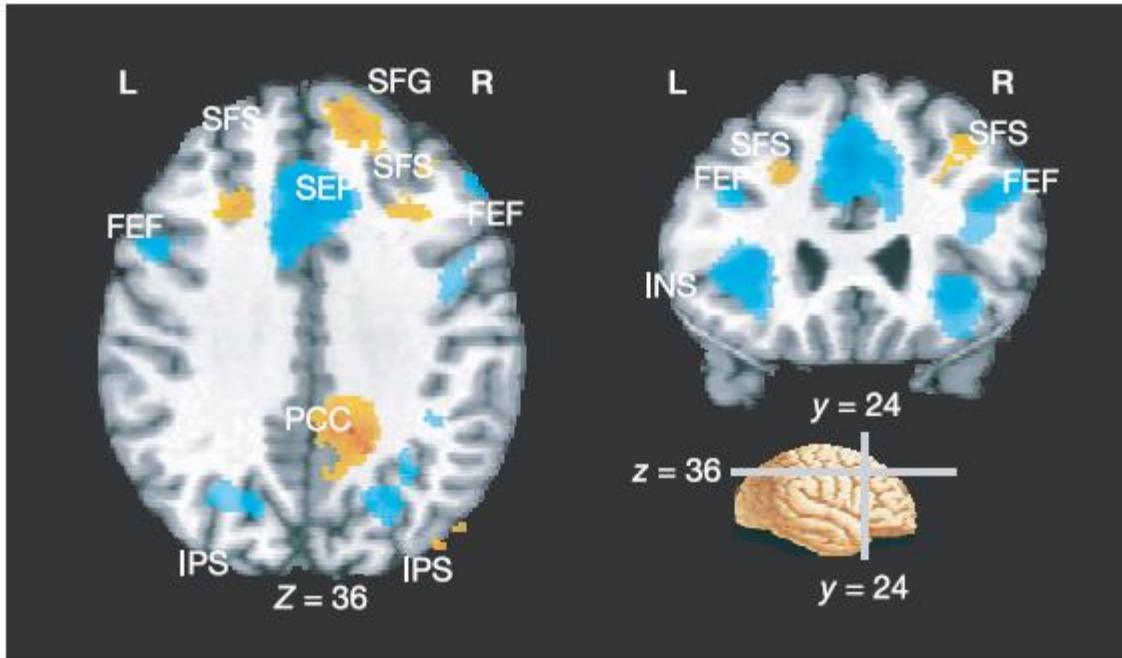
Figure 3 Brain regions showing a main effect of task difficulty: orange: easier (low noise proportion) > harder (high noise proportion); blue: harder > easier. FEF, frontal eye field; INS, insula; IPS, intraparietal sulcus; PCC, posterior cingulate cortex; SEF, supplementary eye field; SFG, superior frontal gyrus; SFS, superior frontal sulcus.

EFFECT of TASK DIFFICULTY:
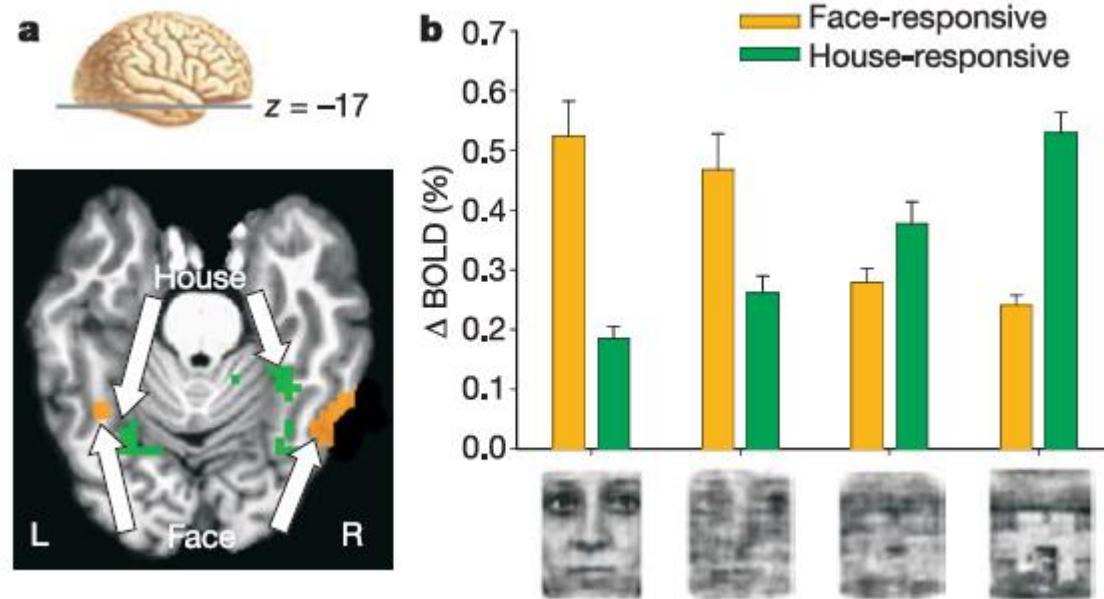
Orange easier (low noise proportion)
- **PCC → posterior cinculate cortex**
- **SFS → superior frontal gyrus**

Blu harder (high noise proportion)
- **FEF → frontal eye field**
- **SEF → supplementary eye field**
- **IPS → intraparietal sulcus**

Perceptual decision making in the brain

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Figure 2 FMRI data illustrating representation of sensory evidence in maximally face- and house-responsive voxels. **a**, Maximally face- (Face, orange) and house-responsive (House, green) voxels in one subject. **b**, BOLD change corresponds to perceptual evidence for respective classes of stimuli. Mean responses ($n = 12$, error bars represent standard error of the mean) in face- and house-selective voxels to the four different conditions (from left to right: suprathreshold face (~10% noise), perithreshold face (~45%), perithreshold house (~53%), suprathreshold house (~10%)). For the respective preferred category, both face- and house-selective regions responded more to suprathreshold than to perithreshold images (face-selective: $P < 0.041$, paired t-test one-tailed; house-selective: $P < 0.001$) while the opposite was true for the non-preferred category (face-selective: $P < 0.013$; house-selective: $P < 0.002$). For face-responsive: suprathreshold face > perithreshold face > perithreshold house > suprathreshold house (analysis of variance, linear contrast, $P < 0.001$); for house-responsive: opposite pattern ($P < 0.001$).

Authors identified voxels in the **ventral temporal cortex** that responded more to faces than to houses, and vice versa, in each subject (Fig. 2a, 'Face' and 'House').

If the activity of the house detector is larger than the activity in the face detectors → we decide that we see houses.
If the activity of the face detectors is larger than the activity of the house detectors → we decide that we see faces

Perceptual decision making in the brain

NATURE | VOL 431 | 14 OCTOBER 2004 | www.nature.com/nature

A general mechanism for perceptual decision-making in the human brain

H. R. Heekeren[1], S. Marrett[2], P. A. Bandettini[1,2] & L. G. Ungerleider[1]

DLPFC as "computational" unit

Activity in DLPFC is proportional to the difference in the activity of the face and the house detectors
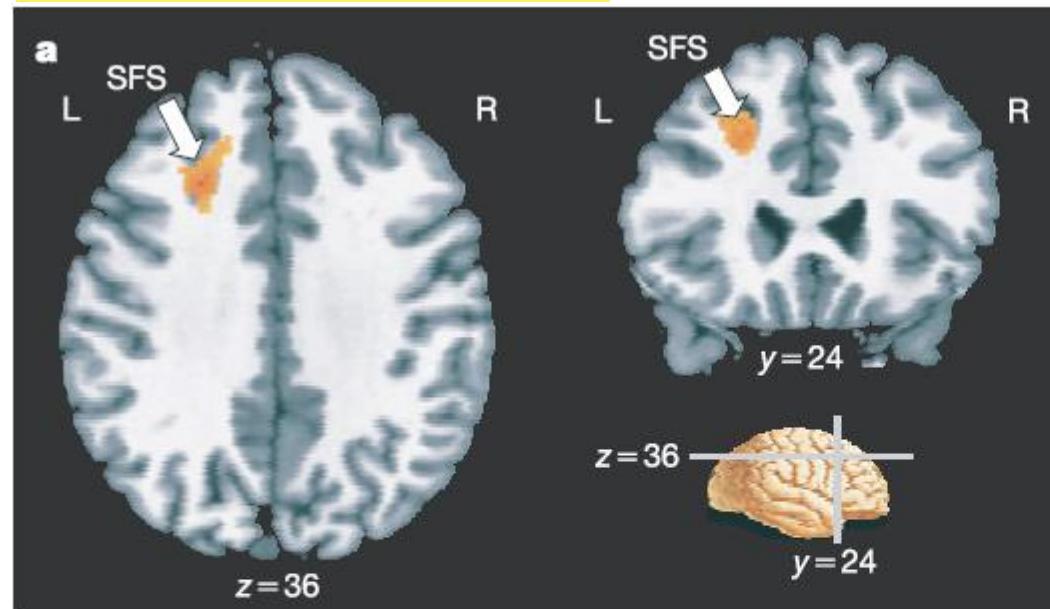
Figure 4 Perceptual decision-making in posterior DLPFC. **a**, Region in the depth of the left SFS, showing both a higher response to suprathreshold images of faces and houses relative to perithreshold images, and a correlation with |Face(t) − House(t)|, suggesting that this brain region integrates sensory evidence from sensory processing areas to make a perceptual decision (BA8/9, easier > harder: $x = -24/y = 24/z = 36$, $z_{max} = 4.20$; correlation with |Face(t) − House(t)|: $x = -22/y = 26/z = 36$, $z_{max} = 3.66$, coordinates in MNI system refer to local cluster maxima, and z_{max} to the corresponding z-value). **b**, Signal changes in the posterior portion of the DLPFC predicted task performance ($r = 0.413$, $P = 0.004$). Points represent average BOLD change and performance for each condition (suprathreshold face, perithreshold face, perithreshold house and suprathreshold house) and subject.

Perceptual decision making in the brain

A general mechanism for perceptual decision-making in the human brain

H. R. Heekeren[1], S. Marrett[2], P. A. Bandettini[1,2] & L. G. Ungerleider[1]

- DLPFC performs the computation that provides this decision.

- This region fulfilled the two conditions implicit in the Shadlen model of perceptual decision-making:
  1. First, the region showed **greater activity** during those trials in which **more sensory evidence for one of the alternative categories** was available (suprathreshold versus perithreshold stimuli).
  2. Second, the activity in this region was correlated with the absolute difference between the signals of face- and house-selective regions.
  3. Finally, signal changes in this region predicted task performance

Perceptual decision making in the brain

- Perceptual decisions are based on an integrative process in which sensory evidence accumulates over time until an internal decision bound is reached.

- The authors used repetitive transcranial magnetic stimulation (rTMS) to provide **causal support for the role of the dorsolateral prefrontal cortex (DLPFC) in this integrative process**

Causal Role of Dorsolateral Prefrontal Cortex in Human Perceptual Decision Making

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Task: perceptual categorization task (presented noisy pictures of faces and cars and subjects had to decide)

Perceptual decision making in the brain

rTMS suppression of DLPFC

**Causal Role of Dorsolateral Prefrontal Cortex in Human Perceptual Decision Making**
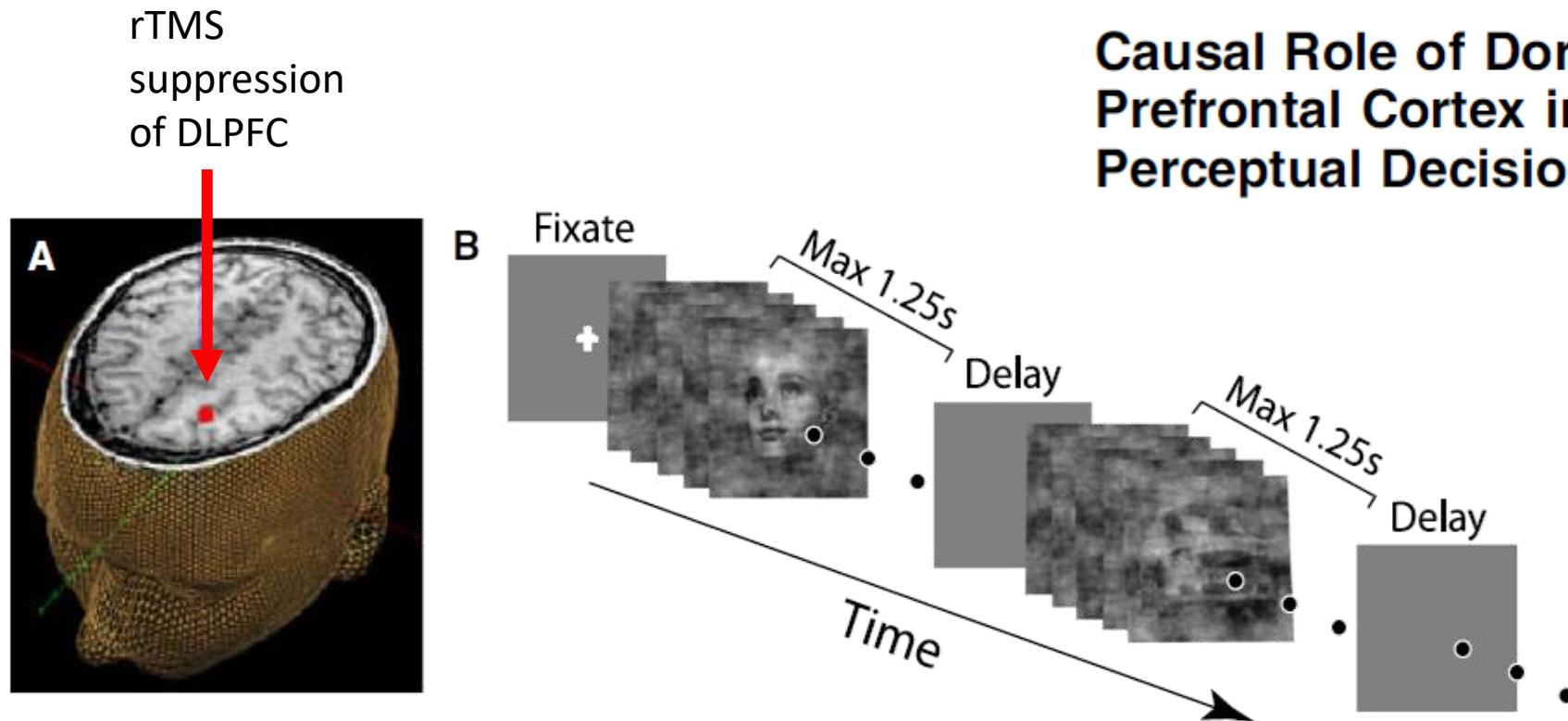
Figure 1. rTMS Target Site and Behavioral Task

(A) A region within the superior frontal sulcus, in the left dorsolateral prefrontal cortex (MNI coordinates: −22, 26, 36; red circle), as reported previously by Heekeren and colleagues [8, 9] using functional magnetic resonance imaging experiments.
(B) Schematic representation of the behavioral task. See Supplemental Experimental Procedures for more details.

Perceptual decision making in the brain

A First Half **B** Second Half

Proportion Correct — SHAM / TMS

C **D**

Mean RT (ms)

L   H
Sensory Evidence

L   H
Sensory Evidence
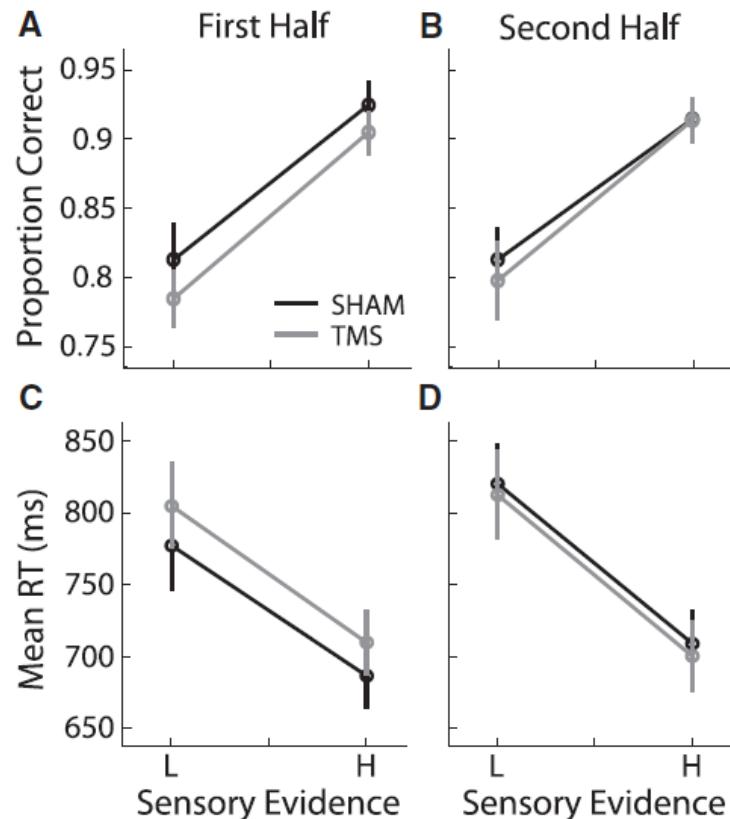
Figure 2. Behavioral Performance
Mean accuracy (A and B) and mean response time (RT) (C and D) across participants for the two levels of sensory evidence (L, low; H, high) and for each of the rTMS and sham conditions, separately for the first (A and C) and second half (B and D) of trials. Error bars represent standard error of the mean.

Causal Role of Dorsolateral Prefrontal Cortex in Human Perceptual Decision Making

- Disruption of the left DLPFC with low frequency rTMS reduced accuracy and increased response times relative to a sham condition.

- These results provide causal evidence linking the DLPFC to the mechanism of evidence accumulation during perceptual decision making.